Medicine in Perspective

Trench Foot—A Study in Military-Medical Responsiveness in the Great War, 1914-1918

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Along the nearly 15,000 miles of trenches on the western front in the Great War of 1914-1918, a condition known as "trench foot" caused serious attrition among the fighting troops and resulted in swollen limbs, impaired sensory nerves, inflammation, and even loss of tissue through gangrene. Physicians, sanitarians, and military officers explored numerous theories regarding etiology and treatment before focusing on a combined regimen of common-sense hygiene and strict military discipline.

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The Great War on the western front began as a war of movement. In early August 1914, German armies swept through Belgium, and by August 24, an extensive retreat of the Allied armies sent shock waves through the capitals of Europe. In September, however, the German advance halted with the battle of the Marne, which was quickly followed by a race to the sea (October 10 to November 10), with the German and French armies attempting unsuccessfully to outflank each other. By the end of the first battle of Ypres (October 30 to November 24), the western front had become fairly well fixed, confined largely to trench warfare, which endured for nearly four years.[1-3]

Eventually, more than 15,000 miles of trenches stretched in zigzag fashion from the North Sea to the borders of Switzerland and became the killing ground for soldiers on the western front. The battle lines between the belligerent powers settled into a stalemate in which opposing armies dug in like rabbits, living an almost subterranean life and fighting each other across a narrow "no-man's-land" in harrowing but futilely destructive encounters. For soldiers, the trench became home, the line of defense, and, unless kept dry with boards or lime to cover the trench bottom and walls, a veritable incubator for bacterially spread diseases and other incapacitating problems. Although troops in the Great War fared better in terms of general health than in any previous war in history, trench warfare introduced its own special diseases and characteristic war wounds. Besides trench fever, tetanus, head wounds and shell shock from artillery barrages, and gas gangrene, soldiers experienced an inordinately high rate of so-called frostbite or trench foot. Of all diseases grouped under the etiologic title "physical environment," frostbite and trench foot were of principal importance, causing serious attrition in the field armies. Because these maladies interfered with a soldier's ability to march, they also "became the touchstone of health discipline."[4(p90)]

Early Days of War

Between October 25, 1914, and March 10, 1915, the war theatre experienced an unusually wet season, with only 18 days of dry weather. Rain became the implacable enemy of both armies, and the trenches, which then consisted of many natural ditches, flooded with water. Although the terrain varied considerably along the 475 miles of front, most soldiers found themselves living ankle deep in mud except for a few months in summer. And in the weeks after the first battle of Ypres, soldiers held an extended line for hours on hours in water and mud up to their waists or even their armpits.

The conditions of trench warfare included nervous strain and long hours of inactivity, with men remaining almost motionless and in cramped positions, immersed in mud or cold water at near-freezing temperatures. As the temperatures fell, those standing knee deep in ditches faced actual freezing, and field ambulances reported treating cases of frostbite. Even with improved weather conditions, physicians found themselves not treating actual frostbite but characteristics that were clinically indistinguishable from frostbite and which they initially called "chilled feet" or "trench foot."[5(p600)]

The typical medical history of trench foot began with soldiers feeling their feet becoming cold and then ultimately losing all feeling. Beyond the initial discomfort associated with cold feet, there was no other complaint until the feet swelled around the ankles, the swelling sometimes extending up the calves. At this stage, soldiers could not replace their boots once they had been removed. It was thus not unusual to see men in a battalion hobbling along in their bare feet or in boots that were too tight to lace. In moderate cases, the condition lasted two to three weeks, but the more severe cases lasted from six weeks to three months or more.[6(p1143)]

Among soldiers diagnosed with trench foot, many had worn their boots and puttees for periods from 72 hours to 14 days without taking them off. Often, boots that were large when dry had shrunk under the wetness. "Within a few minutes or even before entering the trenches for their spell of days and nights of fighting," wrote one medical observer, "the boots of the majority of my patients had been soaked, and so they remained until, on their removal, the gangrene or other manifestations were discovered."[7(p38)]

The field ambulance workers soon had on their hands men whose feet were not just swollen but showing color

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change, from bright pink blush to a dead, black gangrenous appearance. In some, the skin was covered with a bullous eruption. In almost all instances, the disabling effects resulted from exposure to water when the temperature was above the freezing point. Only a small number—less than 10%—suffered from classic frostbite or actual freezing of the tissues.[5(pp602-603)]

In the winter of 1914, S. Delepine, Professor of Public Health and Bacteriology and Director of the Public Health Laboratory at the University of Manchester, initiated a study of the effects on hands and feet immersed in water above or below the freezing point. He divided his experiments into two groups: those unprotected from wet cold and those for whom protection had been provided.[8(p176)]

From his clinical and experimental data, Delepine concluded that "neither exposure to a freezing temperature, nor congelation of the tissues are necessary factors in the production of the pathological state generally known by the name of frostbite." The severity of lesions in so-called frostbite was determined not only by the intensity and duration of the cold but by other predisposing factors including imperfect circulation, lack of exercise, water, and stress. The name frostbite suggested "a destructive lesion due to the action of frost," but Delepine considered the term unsatisfactory from a scientific point of view and found most of the alternative names equally unsuitable. Although the word trench foot became the choice of European physicians—the Americans continued to use the term frostbite—this term, along with "water bite," "chilled foot," and "boot bite," failed to meet the needs of scientific nomenclature. Instead, Delepine proposed the term "frigorism," which he defined as a state of the body "produced when the cooling of the body or any part of it is progressive—that is, when it cannot be compensated by the production in the tissues, and the distribution by the circulating blood, of a sufficient amount of heat." When the cooling of a body extremity reached a certain critical point, the natural functions of the tissues stopped and freezing occurred, thus creating additional complications that affected the actual state of the cells and fluids.[8(pp173-174),9(p888)]

In studies undertaken by the British Medical Department, physicians not surprisingly found that the instances of trench foot coincided with cold and wet weather. Of interest, however, the highest number of cases occurred during October and November, falling off in December and January during the freezing weather and rising again after the thaw. During the first year of the war, one battalion lost 400 men in two days to trench foot, and many of these men suffered subsequent amputations. Physicians treating these cases soon began dividing them into three different groups: The first type they characterized as functional anesthesia with impairment of movement; a second type showed slight edema, functional anesthesia, and impairment of movement; the third type exhibited well-marked edema, bleb formation, and ecchymoses.[5(p598)]

Pathology and Etiology

The etiology of trench foot remained confused through most of the war years. While some medical authorities expressed the opinion that the condition derived from actual freezing of the tissues, others attributed it to the loss of vitality in the limbs resulting from water soaking into the tissues. Still others pointed to a fungus or mold found in soil, straw, and manure that entered through lesions in the feet. One enthusiastic writer even ascribed trench foot to "the leaking, through wet feet, of the electrical energy manufactured by the central nervous system." To correct this disorder, he proposed the use of "dielectric oil." Despite the different approaches, all agreed that trench foot thrived best at low temperatures and high moisture.[5(p601)]

In instances of classic frostbite, the skin tended to swell after thawing, becoming red and covered with blisters. Later, portions of the skin or deeper tissue died and separated as a dry gangrenous mass. In these cases, the amount of tissue lost depended in large measure on the duration of cold and the temperature reached inside the tissues. During the thawing process, patients experienced intense pain, followed by tingling and itching of the affected parts. Any healing was complicated by swollen tissue cells, impaired sensory nerves, and inflammation.[7(p36)]

In situations not involving actual freezing of the parts but, rather, long exposure to cold and dampness, the effects were to be seen in the vascular and lymphatic systems. Minor chilling of the exposed superficial parts affected the smaller arteries and later the larger and deeper arteries, resulting in a vasoconstriction in the extremities. When this occurred, a soldier experienced pain from the effects of cold on the nerve endings, and the body movements became hindered. Eventually, vasodilation followed vasoconstriction, and the parts became red and erythematous or blue, vivid, cyanotic, and congested. Over time, continued exposure to wet and cold caused the skin to blister and ulcerate, with a tendency to infection and loss of tissue through gangrene. German writers identified this condition as frost gangrene in the absence of frost.[7(p37),10]

Early in their classification of types, physicians voiced the opinion that imperfect circulation brought on by surface chill, general muscular inactivity, and tight-fitting boots were the principal pathogenic factors in the establishment of trench foot. Helpful in this analysis were the ample data available as physicians and sanitary personnel examined hundreds of soldiers of the same relative age and health, who were wearing the same types of boots, socks, and puttees, and who had been standing in freezing mud or water for hours at a time. Their examinations of these men provided a consistent level of data enabling them to generalize the early symptoms of numbness, functional anesthesia, and swelling.[8]

The similar pathologic features of trench foot with those of Raynaud's disease did not go unnoticed. Two varieties of the disease, the blue congested and the white, were reproduced almost exactly among soldiers in the trenches. Of the two, the blue congested form predominated, but a certain number also evidenced the "dead white foot." Both suggested an underlying vasomotor condition. "I have admitted cases in which the feet were white, numb and shrunken, and which shortly afterwards were found to be swollen and blue," remarked one observer. "This would suggest that the condition, commencing as a vasomotor constriction, passes on to vasomotor paresis and paralysis, with damage of the capillary walls, and consequent hemostasis, exudation and finally gangrene."[5(p600),11(p664)]

Early efforts to substantiate a bacterial cause of trench foot indicated that a bacterial invasion resulted from lowered vitality of the foot from cold. This thesis, put forward by Gordon Watson and others, found its greatest acceptance with the French medical community, which attributed the

condition to a fungoid infection of the epidermis and the subsequent invasion of the devitalized dermis by mycelium. Advocates of the thesis suggested that the bacterial invasion was not the first cause of the condition but rather a secondary one. The growths obtained by culture were of organisms present in mud that became pathogenic in devitalized tissues. French scientists claimed to have isolated from the gallbladders of patients who died an organism called a "mycosis" that, when inoculated into rabbits, produced skin lesions resembling trench foot. The Inspector General of the French Army issued a general circular noting a microbic origin, the agents of which were isolated from trench mud. Experiments on animals reproduced various symptoms associated with trench foot, suggesting that the disease was similar to mycetoma, the fungus foot of Madura that English surgeons had named "tuberculous foot."[5(p601),6(p1143),11(p665)] To prevent this, physicians recommended painting the feet with formalin, using a dusting powder composed of French chalk and zinc oxide, and supplying a generous diet of foods containing nitrogen.[12]

From October to the end of December 1915, Captain Basil Hughes of the Royal Army Medical Corps was attached to a regiment holding a section of the line where the conditions of trench fighting were exceedingly poor. The cases that Hughes studied were almost always identical. During this period, the troops were constantly exposed to rain and, unable to move about, either stood or crouched during the daytime hours and slept in a sitting position at night. He learned that while on duty, the men frequently complained of numbness and a "pins and needles" sensation in the feet. On coming off duty, their feet swelled and were red and tender to touch.[13,14(p298)]

On investigation, Hughes discovered that while the shoes worn by troops were typically a size larger than normally required and socks were frequently changed, the boots nevertheless filled with a "thick soupy mud" that had come in contact with decomposing organic matter. This, he theorized, was the exciter of the condition found in so many of the men. In testing his thesis, Hughes directed soldiers to rub grease and whale oil into their feet, wear clean dry socks, increase their exercise, and wear rubber knee boots when in the trenches. Although the boots prevented the men from coming in direct contact with the mud, Hughes found to his surprise that the incidence of trench foot did not subside. From this evidence, he concluded that the bacteria in the mud were not a factor in trench foot.[13]

An inquiring scientist, Hughes then searched for answers other than a microbic cause. He next considered fatigue and the "consequent collection of waste products of metabolism in the cellular tissues of the lower extremities," thinking that this could be the predisposing cause while cold and wetness acted as the exciters. Accordingly, he ordered hot soup made with fresh meat and vegetables sent to the trenches each night. At the same time, Hughes continued to require the men to wear rubber boots to protect their feet from mud. Socks, however, still got wet from boot condensation. In testing his new thesis, Hughes discovered that the incidence of trench foot declined, and he attributed the change to improved rations.[13]

Still Hughes was not satisfied. On checking other trench lines during the winter of 1915, Hughes found the saps, firebays, traverses, and communication trenches deep and in good condition, with sufficient width to allow men to move about. In making his rounds, however, he noticed that men who sat on the fire-step with their legs hanging down experienced a sensation of numbness and "pins and needles" in their feet and legs. After learning that the experience was a common one, he insisted that the men rest with their feet on the fire-step rather than hanging over it. During the period when these precautions were taken, no incidence of trench foot was reported. Hughes concluded from his observations and actions that two factors produced trench foot. The predisposing factor was fatigue but the exciting factor was purely mechanical, namely, "venous stagnation and consequent exudation of material into the tissues of the foot." Accordingly, he insisted that men in the trenches rest with their legs elevated, that they use blankets when resting on the fire-step, that they change socks frequently, and that they take hot soup and rum to keep up vitality.[13(p713)]

353. Frostbite—Precautions

Cold is likely to give rise to frostbite when the circulation of blood is interfered with or rendered feeble. The feet are likely to be frostbitten under the following circumstances:

1. When boots and puttees are too tight
2. When the general circulation throughout the body is less active than normal
3. When the socks, boots, and puttees are wet.

The best precautions are on the following lines:

1. Boots should not fit tightly but should be at least a size too large. When large boots are worn it is well to wear two pair of socks, but this is dangerous if the boots are small, as it leads to further pressure on the foot. Puttees should never be applied tightly.
2. The general circulation can be kept up by keeping the body warm and dry. A mackintosh sheet worn over the greatcoat is of assistance where no waterproof is available.
3. A dry pair of socks should be carried in the pockets when available. Officers should see that dry standing is provided in the trenches whenever possible by means of drainage, raising of the foot-level by fascines of brushwood or straw with boards on top, or by the use of pumps where these are available.

Figure 1.—The British Army issued these precautions for the prevention of frostbite (from Delepine[8(p175)]).

Prophylaxis

In response to the high incidence of frostbite and trench foot, the British Army issued Army Routine Orders, dated November 23, 1914, outlining steps to prevent frostbite (Figure 1).

Ideally, dry weather and good drainage in the trenches eliminated the problem of trench foot. Such an environment, however, seldom prevailed under battle conditions. Constant bombardment and the need for readiness often precluded efforts to pump out saps, fire-bays, traverses, and communicating trenches. The military initiated efforts to drain the trenches and provide them with boards—known as "duckboards"—placed at the base of the trench. By 1915, miles of duckboards were laid in the trenches, many of which either floated away with the heavy rains or were trodden into the mud.[5]

More effective prophylaxis involved thorough foot and boot inspection of soldiers before they entered the trenches, the systematic use of soap, water, and "French powder" (borated talc and camphor), oiling the feet, and insisting that boots be well greased and of ample size so as to ease pressure on the feet when wet. Additional precautions included loose-lacing of the boots as well as loose-binding of the puttees to

ensure adequate circulation. Physicians were quick to point out the problems of puttees; when wet, they constricted circulation to the legs and tended, in cold weather, to freeze. Other measures included wearing clean dry socks, filling the boots with hot bran or hot crumpled newspapers to absorb water, exercising whenever possible (in some instances, soldiers lay down on a tarpaulin in the trenches and did overhead feet exercises), even if it only meant stamping their feet or moving their toes within the boots, and placing dry sandbags over the feet or securing bags stuffed with straw around the legs and feet.[5,11,15] Finally, Hampstead Hospital, which initiated some of the earliest studies of classic frostbite and trench foot, recommended the liberal use of salted lard, which protected the feet against water and also acted as an antiseptic.[16(pp635,640)]

In situations where soldiers had little time to check each of these items, they often simply poured oil of mustard into the top of their boots because it conveyed the sensation of heat to the feet. Whale oil was another popular prophylaxis within the British and Australian armies. Those battalions whose incidence of trench foot was lowest attributed their success to both the whale oil and the general measures that were enforced around its use, such as frequent removal of boots and socks, careful supervision by officers, and using friction and rubbing, which helped circulation.[4(p100)]

Gum boots with india rubber extensions and waders were available to the British Army in 1915 and 1916 and distributed on a scale of 2,500 per division. Nevertheless, many in the military considered them too cumbersome and expensive for widespread use. Moreover, during periods of marching, the legs and feet perspired profusely, subjecting them to the very conditions that the boots were intended to avoid. The solution, as some officers were to discover, was to put on the gum boots *after* arriving at the trenches to avoid the risk of their becoming wet from condensed perspiration.[14(pp296-297)]

Others turned to alternative methods such as adopting Labradorian footgear consisting of two or three layers of watertight skins. Within certain British lines, soldiers wore boots large enough to permit the wearing of at least three pairs of socks—an inner, light pair soaked in a salted ointment and two heavy woolen outer pairs dipped in paraffin.[17] Major Grenfell's experiments in Labrador and Newfoundland over a 25-year period showed the effectiveness of layered clothing that permitted the body to breathe through the garments. Grenfell opposed the use of india rubber boots or other waterproof garments because they held moisture when the body exercised.[8]

Another alternative involved the use of thin oil-silk fabric waterproofed by oxidized linseed oil. Experiments on the permeability of oil-silk of various thicknesses and with the addition of resins, neutral fats, and paraffin wax resulted in a preference for linseed oil boiled with a lead salt.[9] The use of oil-silk bags involved the wearing of a dry woolen sock, as thick as possible but not tight fitting, drawn over the dry and warm foot powdered with French chalk. An oil-silk or "antifrigor" bag, as it was sometimes called, was stretched over the sock, followed by a second sock that was not thick but sufficiently large. A soldier then wore boots at least two sizes larger than his regular foot size.[5]

Treatment

When local freezing occurred, physicians first used friction with snow or cold water rather than immediately inducing warming. Friction with turpentine and oil or spirits and soap liniment was also used in the early stages of treatment, followed by maintaining the affected parts in a dry, warm, and aseptic environment. In situations not involving actual freezing, physicians typically wrapped the limbs in wool, kept them in a raised position, and powdered them with a dusting material such as zinc oxide, boric acid, and iodoform, or painted them with a 2% solution of iodine. In addition, physicians encouraged active movement of the feet and legs to increase vascularity to the feet and recommended massage, mild applications of hot air, and treatment with static electricity.[7(p49)]

As the cause changed, physicians turned to internal doses of potassium iodide and the external use of tincture of iodine and salvarsan—methylene blue. Wet dressings soaked in borated camphor solution worked better than dry dressings. Raymond and Parisot claimed success by washing the feet with warm water and a mixture of green soap, camphor, and borate of soda.[18] This was followed by carefully drying and covering the feet with a layer of absorbent cotton soaked in a solution of camphor and borate of soda. The area was then covered with oiled silk or a rubber sheet, with the dressings changed each day. In addition, because tetanus occurred frequently, physicians administered antitetanic serum to all patients. With the vesicular form of trench foot, physicians recommended denuding the area of its gelatinous character and covering it with compresses soaked with camphor in ether. In the worst cases, surgeons removed the purulent layer or fetid edema fluid, washed the area thoroughly with antiseptic solution, then applied camphorated ether. Surgeons preferred amputating at a healthy point beyond the infected area. The most frequent complication was tetanus, while gas gangrene was also prominent.[6]

Retrospect

Although the prophylactic measures undertaken by physicians on both sides of the trenches improved measurably the health of the soldier and reduced the incidence of trench foot, the military eventually realized that much of the problem derived from hygienic negligence among officers and men or, as Macpherson noted in the official documents of the Great War, the failure of "making . . . a fine art of the 'toilet' of the feet."[14(p295)]

Eventually, officers across the western front developed elaborate organizational arrangements to ensure fresh supplies of socks to men in the trenches. Waterproof bags full of clean dry socks were sent every night to the trenches along with the rations. This enabled every soldier to receive a fresh pair of socks every 24 hours. To maintain circulation and avoid any form of constriction of the feet and legs, officers prohibited the wearing of puttees in the trenches and encouraged the men to move about as much as possible. Some even instituted a regular removal of the boots, followed by foot-rubbing drills and massage. Officers also insisted on correct posture when sitting on the fire-step or crouching against the wet side of a trench. Other changes included the rule that trench duty in a water-logged sector should not exceed 24 to 36 hours; the institution of "foot-washing centres"; a liberal ration of hot food in the trenches; removing boots and socks at least twice a day while in the trenches; the more extensive use of gum boots; and the gradual abandoning of greasy preparations for the use of dry foot powder. Nevertheless, British soldiers never completely gave up using their whale

oil. When in the line, a battalion received ten gallons of the oil as its daily issue.[14(pp299,480-481,484-486)]

Most important, the army placed the responsibility for the proper care of the men's feet on company and platoon officers rather than on the medical corps. The Fourth Army's Standing Order No. 595, issued June 20, 1917, stated that "CO's [company officers] will be reminded that the loss of effective strength due to the prevalence of this trouble is an indication of faulty discipline and faulty interior economy, and they will, therefore, be held responsible that the instructions laid down are carried out under the strictest supervision by company officers."[14(p482)] The real secret to preventing trench foot was perhaps best revealed in the comment of A. G. Butler in *The Australian Army Medical Services in the War of 1914-1918:* "The CO and all officers entered enthusiastically into the spirit of the game."[4(p100)] In other words, the successful elimination of trench foot as a major source of attrition turned out to be little more than good morale, common-sense hygiene, and strict military discipline.

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